EXPERIMENTAL INVESTIGATION OF THE EFFECT OF VISCOUS FORCES UPON PITOT TUBE READINGS

C. W. HURD
AND
K. P. CHESKY

1951

EXPERIMENTAL INVESTIGATION OF THE EFFECT OF VISCOUS FORCES UPON PITOT TUBE READINGS

by

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(1951)

Title of Thesis: Experimental Investigation of the Effect of Viscous Forces Upon Pitot Tube Readings.

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ABSTRACT

Conventional interpretation of pitot tube data for the purpose of determining the velocity of fluid flow in the region of the pitot tube is based upon the assumption that the viscous forces acting on a fluid element are negligible compared to inertia forces. The question arises as to what quantitative effect does increasing the ratio of viscous forces to inertia forces have upon conventional interpretation of pitot tube data.

Apparatus, instrumentation, and procedure were devised to determine this effect, and the results are presented as $\frac{p_o - p}{\frac{1}{2}\rho V^2}$ plotted versus the ratio $\frac{Vr}{\nu}$, where p_o is the total pressure, p is the static pressure, V is the velocity of the fluid relative to the pitot tube, ν is the kinematic viscosity, and r is the outside radius of the pitot tube.

The results are compared with the results of other investigators of the problem. The results are in general agreement with those of other experimental investigators and one analytical investigator, but at variance with one analytical investigator.

The authors find that below Reynolds numbers of 35, pitot tube data must be corrected to eliminate pressures caused by viscous forces prior to using Bernoulli's equation to calculate dynamic head. If correction for viscous forces is not made, use of the Bernoulli equation results in an error of 1 per cent at Reynold's number of 35; and as Reynold's numbers are decreased, the error increases, and reaches a magnitude of 50 per cent at a Reynold's number of 5.

Cambridge, Massachusetts
18 May, 1951

Professor Joseph S. Newell
Secretary of the Faculty
Massachusetts Institute of Technology
Cambridge, Massachusetts

Dear Sir:

In accordance with the requirements for the Degree of Naval Engineer, we submit herewith a thesis entitled, "Experimental Investigation of the Effect of Viscous Forces Upon Pitot Tube Readings".

Respectfully,

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to Professor A. H. Shapiro, Massachusetts Institute of Technology, for his valuable advice and assistance. The authors are grateful to Professor F. M. Lewis, Massachusetts Institute of Technology, for his interest and suggestions. The authors are indebted to the personnel of the Boston Naval Shipyard and the Massachusetts Institute of Technology Gas Turbine Laboratory for their assistance with the experimental equipment. The authors also wish to thank Mr. B. B. Rozene, Chemist, Boston Naval Shipyard, for his determination of the fluid viscosities.

TABLE OF CONTENTS

NOMENCLATURE

g	32.173 fps^2	Acceleration of gravity - local
p_x	psig	Pressure due to viscosity
p_v	psig	Dynamic non-viscous pressure
p_o	psig	Stagnation pressure
p	psig	Static pressure
R	ft	Rotating arm radius - mean
r	ft	Pitot tube radius
t_f	^{o}F	Fluid temperature
V	fps	Pitot tube velocity
h_s	cm	Glass tube fluid level - static
h_d	cm	Glass tube fluid level - dynamic
h	cm	Change in glass tube fluid levels
Re_r	-	Pitot tube radius Reynolds number
T	sec	Time
N		Number of revolutions
γ		Fluid specific gravity at t
μ	SUS	Fluid absolute viscosity at t
ν	ft^2/sec	Fluid kinematic viscosity at t
ρ	$lb\text{-}sec^2/ft^4$	Unit mass of fluid
ω	rad/sec	Angular velocity of rotating arm

[illegible]

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INTRODUCTION

Application of the Bernoulli equation to pitot tube data for determination of velocity of fluid flow in the region on the pitot tube depends upon the assumption of non-viscous isentropic flow. If p_o is the total pressure and p is the static pressure at the face of a pitot tube placed normal to a moving stream, the assumption that viscous forces acting on a fluid element are negligible compared to the inertia forces leads to the following equation:

$$p_o - p = 1/2 \rho V^2.$$

It appears that this assumption is valid for most flow conditions encountered in practice. The question arises, however, as to what ratio of inertia forces to viscous forces does conventional use of the Bernoulli equation fail to indicate actual velocity of fluid flow.

The objective of this thesis is to obtain quantitative data from a given pitot tube, subjected to varying Reynold's numbers of flow, of the dimensionless quantity $\frac{p_o - p}{\frac{1}{2}\rho V^2}$, and thereby establish the effect of viscous forces upon that quantity.

The problem investigated is a basic one. The pitot tube is used widely for instrumentation in science and engineering, and flows with Reynold's numbers low enough for viscous influence on pitot tube readings are being encountered in studies of the aerodynamics of rarified gases and flows in or near boundary layers. Without listing various situations in which sufficiently low Reynold's numbers may occur, it is of considerable interest to find that pitot tubes do

[illegible]

[illegible]

$$[illegible]$$

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[illegible]

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[illegible]

[illegible]

[illegible]

give "erroneous" readings at low Reynold's numbers and to find the magnitude of the "error".

The problem has been investigated by Tsien;[1] Chambré;[2] Barker;[3] Homann;[4] and Gerdes, Brooks, and Kalina.[5] Barker made an experimental investigation in 1922. Homann made an experimental investigation in 1936. Tsien and Chambré made analytical investigations in 1948. Gerdes, Brooks, and Kalina made an experimental investigation at low Reynold's numbers in 1950.

The results of their investigations are presented in the findings, and compared to the results of the authors.

DESIGN OF THE APPARATUS

A study of the work of previous investigators, advice from the thesis supervisor, and the authors' analysis of the problem indicated certain specifications had to be met in order to realize good quantitative data. Temperature of the fluid should be held constant in order to avoid viscosity changes while data was being taken. The static pressure should be held constant or cancelled out. The speed of flow should be a controlled variable, easy to determine accurately, and should be held constant for any given run. The fluid should be clean and free of any particles of air inclusions. There should be minimum interference of the pressure field surrounding the pitot tube. The flow should be laminar, and streamlines should be perpendicular to the face of the pitot tube. The velocity of the streamlines should be great enough to insure that small errors in reading pressure data would have small percentagewise effect compared to $1/2\rho V^2$.

It was considered that apparatus similar to a model basin for testing the esistance of model ships would nearly meet these specifications. The fluid would then be stationary and in a steady state. The pitot tube mounted on a carriage moving at a known constant speed, immersed a known constant depth into the fluid, could be attached to a manometer; and after a time for response, the dynamic head could be read. By varying fluid viscosities and carriage speeds it was visualized that very good data could be obtained in this manner.

Such apparatus as mentioned above obviously could not be attained, so the authors decided to approach such an ideal as nearly as possible. For the model basin of indefinite length was substituted

[illegible]

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[illegible]

[illegible]

[illegible]

a circular trough. For the carriage on a track of indefinite length was substituted an arm attached to a rotating mechanism in the center of the circle described by the trough. A relatively small amount of fluid could fill the trough, and the pitot tube could move in the fluid until steady state conditions prevailed and data could be taken. Reynold's number could be varied by changing the viscosity of fluid in the tanks or the rotative speed of the arm.

The apparatus as proposed is illustrated in Figure I. In the equilibrium stationary condition, with full fluid contact between the fluid in the tank and that in the glass tube, the level of the liquid in the glass tube is the same as that in the tank. If the fluid is nonviscous, and remains stationary in the tank, then rotating the apparatus so the pitot tube travels through the fluid will result in no change in the level of liquid in the rotating glass tube. The reason for this is as follows: At the face of the moving tube the dynamic pressure is $1/2\rho V^2$ due to its motion through the fluid. The pressure at the face of the tube at any given radius due to centrifugal forces is $1/2\ R^2\omega^2$. But at any given radius the streamline velocity V is exactly equal to $R\omega$. Therefore the pressure due to centrifugal forces exactly cancels the dynamic pressure, and the liquid level is constant at all speeds. If the fluid now is made more and more viscous, the level of the fluid in the glass tube will rise higher and higher, at constant speed, and the height of the rise over the initial static reading will be proportional to the pressure due to the viscous effect.

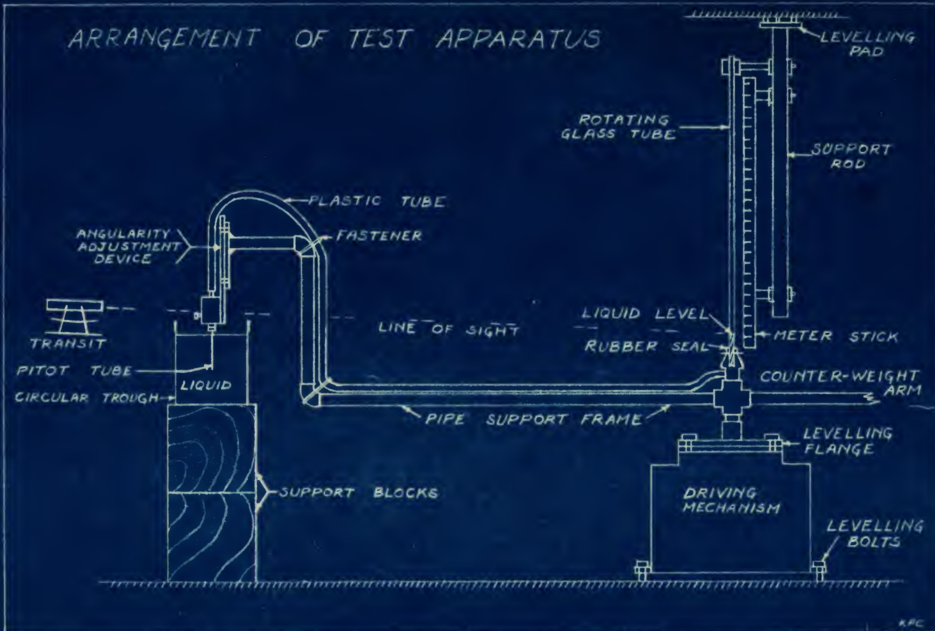

ARRANGEMENT OF TEST APPARATUS
LEVELLING PAD
ROTATING GLASS TUBE
SUPPORT ROD
PLASTIC TUBE
FASTENER
ANGULARITY ADJUSTMENT DEVICE
TRANSIT
LINE OF SIGHT
LIQUID LEVEL
METER STICK
RUBBER SEAL
PITOT TUBE
LIQUID
CIRCULAR TROUGH
COUNTER-WEIGHT ARM
PIPE SUPPORT FRAME
LEVELLING FLANGE
SUPPORT BLOCKS
DRIVING MECHANISM
LEVELLING BOLTS
KPC

FIG I

It was decid d to make the diameter of the trough as large as possible for several reasons:

(a). Streamlines would more closely approach uniform parallel relative flow.

(b). The fluid would not remain stationary in the tank, as postulated above, but would assume a flow in the direction of pitot tube motion induced by pitot tube drag. A large diameter would decrease this flow to negligible proportions.

(c). Surface disturbances caused by the motion of the pitot tube would have more time to damp out.

The space available to set up the apparatus, and transportation within the building, limited the trough diameter to ten feet. A cross section area of 8" by 10" as illustrated in Figure II was chosen because it was felt that this was large enough to eliminate any question of pressure field disturbances from the trough walls.

A flat nosed pitot tube of .072" outside diameter was selected as illustrated in Figure III. This tube was selected because it apparently met specifications, was very accurately made, was readily available, and easy to reproduce. It was decided that the apparatus should be arranged so the face of the tube would be immersed about four inches to minimize free surface effects. The tube was mounted on an adjustable head, shown in Figure IV, so it could be adjusted to face the stream lines vertically in the horizontal and tangential planes, and rigidly held in place after adjustment. It was found necessary to streamline the shank of the pitot tube in order to minimize flow disturbance at the surface, reduce vibrations, and give added stiffness.

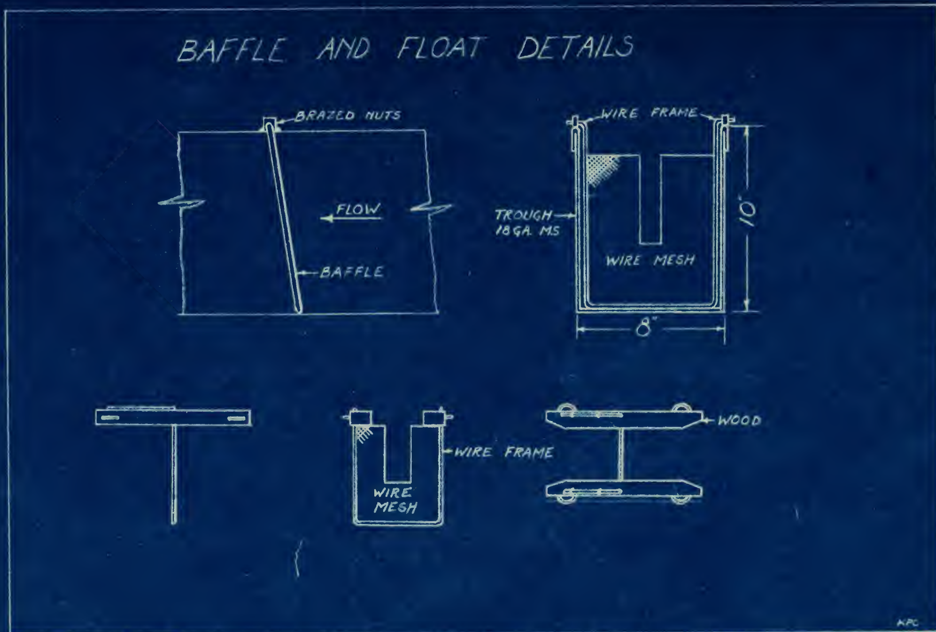

BAFFLE AND FLOAT DETAILS
BRAZED NUTS
FLOW
BAFFLE
WIRE FRAME
TROUGH
18 GA. MS
10"
WIRE MESH
8"
WIRE FRAME
WIRE
MESH
WOOD
KPC

FIG II

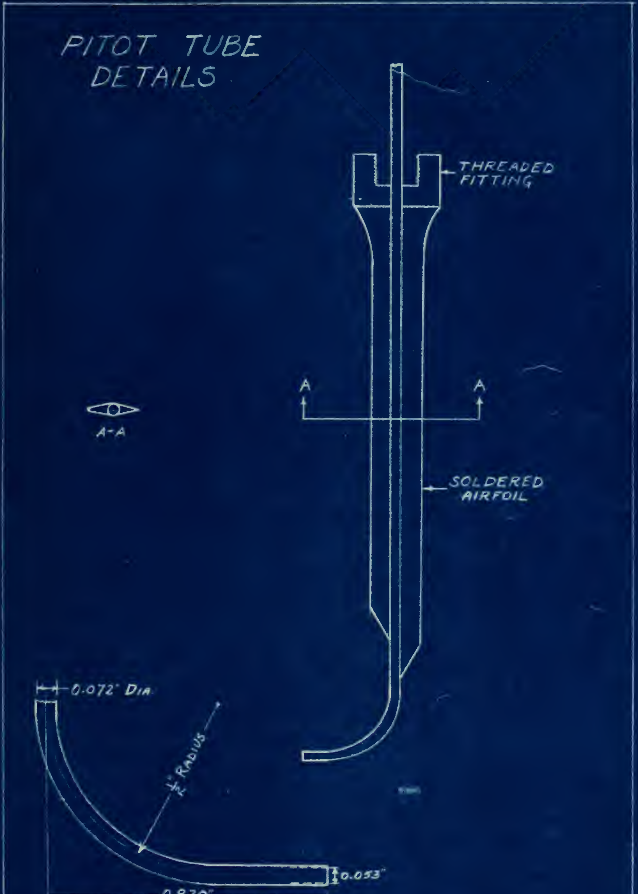

PITOT TUBE
DETAILS
THREADED
FITTING
A
A
A-A
SOLDERED
AIRFOIL
0.072" DIA
1/2" RADIUS
0.053"
0.820"
KPC

FIG III

ANGULARITY ADJUSTMENT DEVICE DETAILS

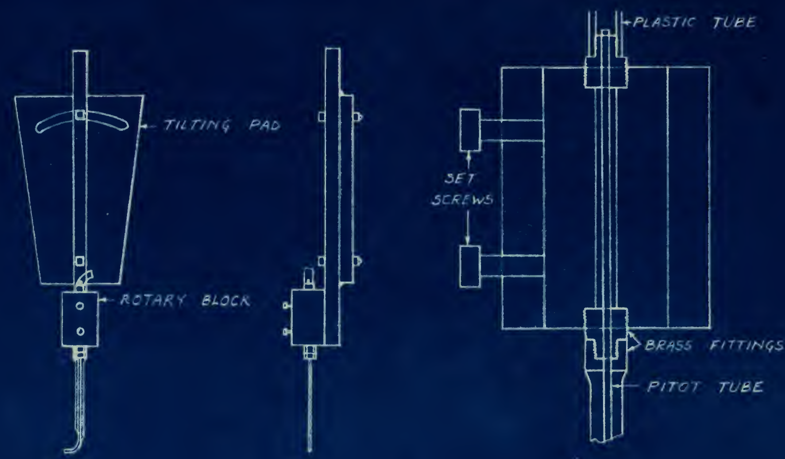


FIG IV

The rotating arm was of one inch standard pipe, and was brazed at all joints after assembly for rigidity. The arm was counterbalanced to avoid centrifugal forces on the prime mover. A plan view of the arm and trough is given in Figure V.

The rotating prime mover selected was a radar antennae drive mechanism made available by the Boston Naval Shipyard, and equipped with necessary controls and auxiliary apparatus to give rotative speeds varying from 1 to 60 rpm.

PLAN VIEW OF APPARATUS

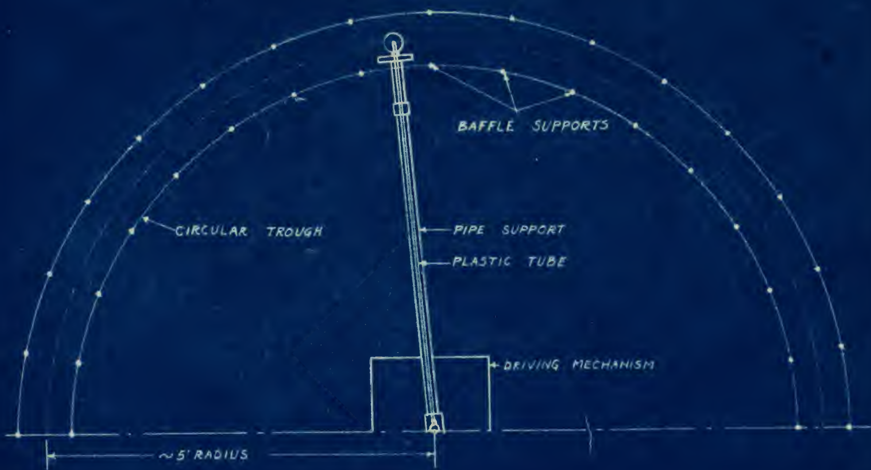


FIG V

ASSEMBLY AND ALIGNMENT OF APPARATUS

The main problem encountered in the assembly of the apparatus was one of alignment. The levelling device at the base of the prime mover enabled placing the axis of rotation of the rotating arm vertical to the surface of the fluid in the tank. The levelling device at the base of the rotating arm and the adjustment device at the base of the vertical glass tube (Figure VI) enabled placing the base of the tube on the axis of rotation. The rod extending from the ceiling was equipped with an adjustable attachment to enable placing the top of the glass tube on the axis of rotation. Thus the axis of rotation passed vertically upward through the center of the rotating glass tube. The tank had to be placed horizontally so its center coincided closely with the axis of rotation, and vertically so the static fluid level was clearly visible in the glass tube.

Most of the alignment was achieved by use of a transit, except that the alignment of the pitot tube in the horizontal plane was done by calibration while making test runs with water in the tank.

After the apparatus was assembled and aligned, test runs were made with water in the tank. A few test runs made it apparent that the authors had underestimated the velocity of fluid motion induced by pitot tube drag. Instead of the level of liquid in the rotating glass tube remaining stationary, it dropped considerably, due to the motion of the fluid.

This difficulty was met by two plans: One based upon measuring the fluid rotation by means of a float, illustrated in Figure II, and correcting the data; and another based on reducing the flow to

LIQUID LEVEL TUBE DETAILS

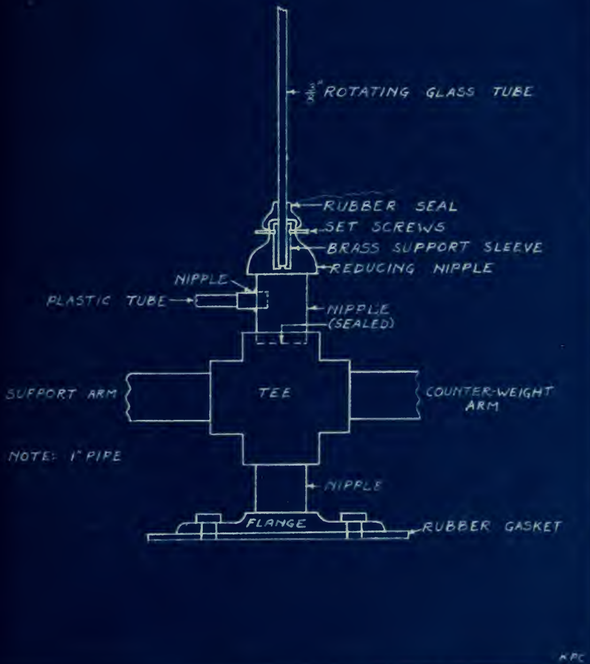


FIG VI

negligible proportions by use of screen baffles illustrated in Figure II. These two schemes were tried with water in the trough. The float reduced the error to about .2 per cent and thirty-two baffles reduced the error to about .4 per cent. Both methods appeared to give suitable results, and it was decided to use both methods.

INSTRUMENTATION

The instrumentation of the apparatus was as follows: A Veeder-Root ratchet counter was installed on the prime mover so the number of rotations of the arm over any period of time could be determined. By use of a stop watch, the period of time for a number of rotations was obtained. The radius of the circle described by the pitot tube as it rotated had previously been measured after completion of alignment of the apparatus. The speed of the pitot tube could then be calculated. The time for the float to make one revolution was timed with a stop watch, and the tank circumference was known; thus the float speed could be calculated. A millimeter scale was mounted on the vertical rod from the ceiling along side the rotating glass tube. A transit was mounted outside the trough,, so that the meniscus of the fluid in the tube could be compared to graduations on the scale with the transit cross hair (Figure VII). Temperature of the fluid was measured with a standard Fahrenheit scale mercury thermometer. Rough checks on kinematic viscosity were made while taking data with a Saybolt viscosimeter, but to insure the best available data on kinematic viscosity, samples of fluid used for each run were analyzed by the Boston Naval Shipyard Chemical Laboratory. Figure VII is a photograph of the apparatus as assembled, aligned, and instrumented, ready for a baffle run.

Figure VIII illustrates the apparatus between runs, baffles out. Sufficient oil from the previous run was drained out of the tank, and the stirring paddle installed on the counter balance arm. As new oil was added to change viscosity, the arm was slowly rotated, so as to mix the old and new oil thoroughly.

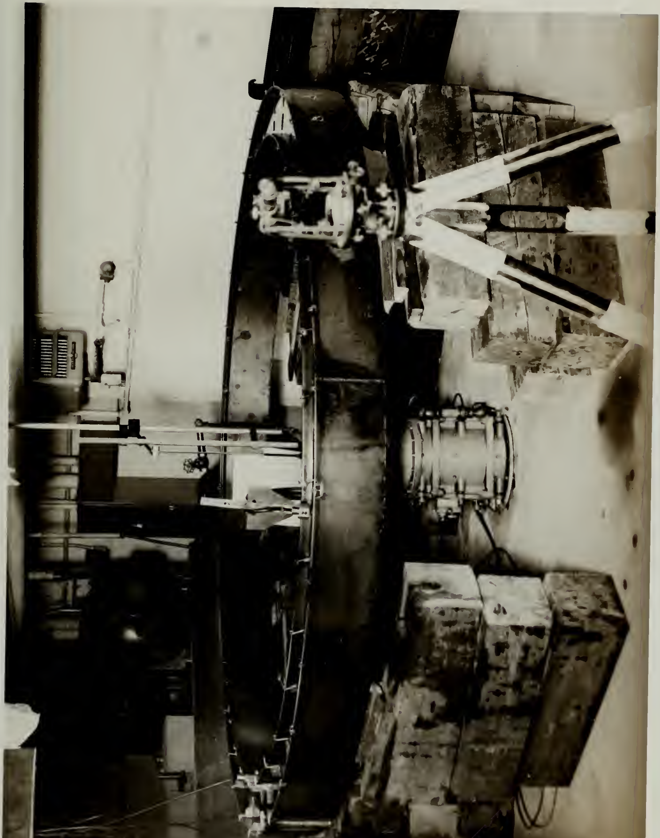


Fig VII

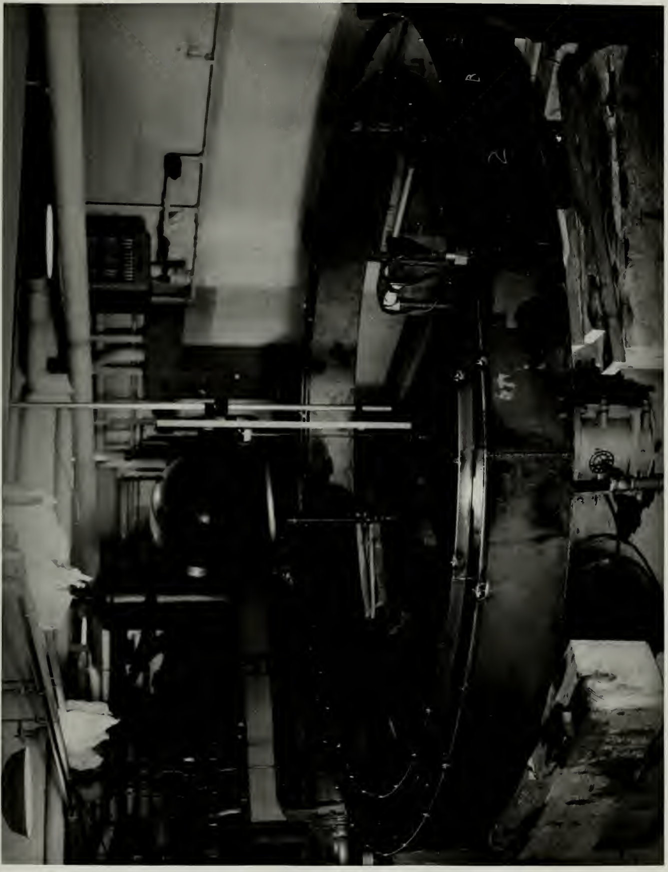


Fig VIII

PROCEDURE

The overall plan for getting data was to run the apparatus so as to obtain pitot tube speeds of 10 to 15 feet per second, and vary Reynold́s number primarily by varying fluid viscosity. This was considered good procedure because higher speeds resulted in large bending forces on the pitot tube, and in the preliminary water runs it was found that lower speeds did not give good float data. Both the float and baffle methods were to be used on each fluid. Kerosene was to be progressively thickened with oil, and data taken after each thickening.

The initial procedure in detail was as follows: Fluid was placed in the tank, and the plastic tube was flushed by introducing fluid from the tank into the top of the glass tube. The rotating fluid circuit, from the glass tube to the pitot tube was purged of all air bubbles. The flushing and purging was to insure that the specific gravity of fluid in the rotating circuit was the same as that of the fluid in the tank. When the level of liquid in the glass tube reached the level of liquid in the tank, a static head was recorded. The apparatus was then started, set to desired speed, and rotated until all conditions had reached equilibrium constant values; that is, the speed, temperature, float speed, and liquid level in the rotating glass tube. When this equilibrium was established, data was recorded as float data. The apparatus was then stopped, the float removed, and baffles were installed. The procedure was then repeated until equilibrium was established, and temperature, speed, and liquid level in the tube were recorded as baffle data.

[illegible]

[illegible]

[illegible]

This procedure was followed until the fluid was thickened to about 200 SUS, and it was discovered that float data was diverging from the baffle data. It was postulated that this was caused by the fact that the curvature of the velocity profile was increasing to such a point that the streamlines propelling the float were moving considerably slower than the streamlines meeting the pitot tube. At this point the float method was abandoned. The rest of the data was baffle data only.

As the taking of data proceeded, it was found that with baffles, slow speeds could be employed as originally planned, and give good results. So, by varying oil viscosity and speeds, a Reynold's number of less than one was reached. Data was not taken to lower Reynold's number because the supply of thick oil was exhausted, and the response was getting exceedingly slow.

The data taken was then reviewed, and found to establish a good curve, but in order to check the data, and better establish its authenticity, it was decided to use kerosene and thinner oils left over from initial runs to decrease kinematic viscosity in steps, and overlap points. This was considered desirable in order to eliminate questions concerning pitot tube bending, alignment, and Froude's number effect. The fluid kinematic viscosity was decreased in two steps, which exhausted the supply of kerosene. This completed the raw data runs.

Samples of each batch of fluid used were sent to the Boston Naval Shipyard Chemical Laboratory for accurate determination of SUS.

Refined calculations were then performed on the data, and the results plotted.

[illegible]

[illegible]

[illegible]

[illegible]

RESULTS

The results in final form are given in Figure IX. Here $\frac{p_0 - p}{\frac{1}{2}\rho V^2}$ is plotted versus the Reynold's number based on the pitot tube radius. The results are also presented as $\frac{p_x}{\frac{1}{2}\rho V^2}$ at higher Reynold's numbers in Figure X, to give a more expanded view of the results in the region of Reynolds number of 40. The method of calculating these quantities is given in the sample calculations, Appendix B, and the data and calculations are summarized in Appendix A.

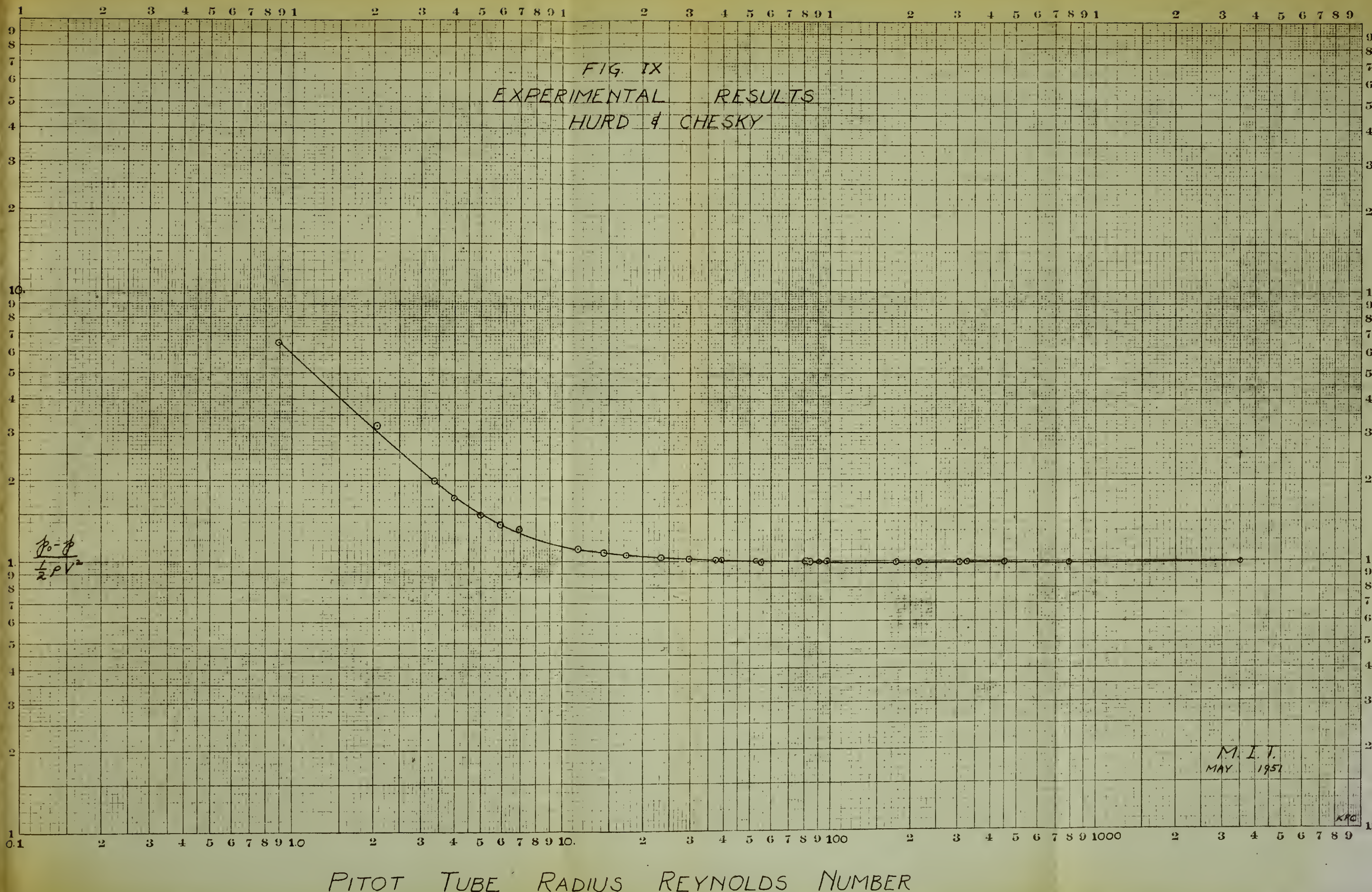


FIG. IX
EXPERIMENTAL RESULTS
HURD & CHESKY
$\frac{p_0 - p}{\frac{1}{2}\rho V^2}$
M. I. T.
MAY 1951
PITOT TUBE RADIUS REYNOLDS NUMBER

DISCUSSION OF ERRORS AND TECHNIQUE

The estimated errors in raw data are as follows:

Item	Error
Radius of pitot tube travel	1/64"
Number of revolutions of prime mover	0
Time readings	.3 seconds
Liquid level in rotation glass tube	.1 millimeters
Saybolt Universal Seconds	.5 seconds
Temperature	.1 degrees Fahrenheit

There were other sources of error, as pitot tube bending and misalignment, rotation of fluid in tank, variation in speed of the prime mover, and collection of particles on the pitot tube.

The source of largest error was considered to be the rotation of fluid in the tank. No entirely satisfactory method was devised to measure the velocity or to eliminate it. Tests with water indicated the rotation accounted for an error of about .4 per cent in the quantity $\frac{p_0 - p}{\frac{1}{2}\rho V^2}$ for baffle runs, and .2 per cent for float runs. As explained in the procedure, the float method was abandoned at about 200 SUS, and the basic data is derived from the baffle method. This means that all baffle points have smaller values of $\frac{p_0 - p}{\frac{1}{2}\rho V^2}$ than the actual value, and larger values of Reynolds' number than the actual. There was no way of determining whether the ratio of pitot tube speed to fluid speed was constant or nearly so for all fluids. From observations of particles in the surface of the fluid, this appeared to be a good approximation, but no attempt was made to correct the data by such an arbitrary assumption. The authors believe it would be safe to assume the quantities $\frac{p_0 - p}{\frac{1}{2}\rho V^2}$ are too small by .2 per cent and the Reynolds numbers are too high by 01 per cent.

[illegible]

The fluid rotation speed was very sensitive to variation in the drag of the pitot tube caused by particles attaching to the shank of the tube as it rotated. This emphasized the necessity of keeping the fluid clean, but in spite of all precautions, some debris would accumulate on the tube. It was noticed, however, that the rate of accumulation was nearly constant, and at speeds below 12 feet per second the accumulation was very small. No readings were taken until the meniscus level in the rotating glass tube was steady, which meant the tube was losing particles as rapidly as it was accumulating them. There was no quantitative way to measure variations caused by drag variations of the pitot tube so the error was accepted as part of the fluid speed error.

It was noticed that the prime mover speed was not constant at all times when there were heavy variable loads on the electrical circuit supplying the apparatus. No data was taken, however, unless successive speed readings were constant. When the circuits were so loaded that no constant speeds could be established, then the authors would take data at night. It is believed that the speed data is accurate to a close tolerance, but there is no way of estimating the error quantatively.

The authors devised suitable methods of aligning the pitot tube, and repeated experiments and calibration runs with water indicated errors due to alignment could be reduced to a negligible quantity.

There was no way of checking the amount of bending experienced by the pitot tube, but data taken at various speeds with different fluids is consistent. This fact should eliminate question of pitot tube bending, because if the tube was bending enough to influence the data, then data taken at high speeds number would not fair in with data

[illegible]

taken at low speeds. Data taken at different speeds and constant geometry indicates the influence of Froude's number due to the free fluid surface is also negligible

Attention was given to the matter of vibration of the pitot tube. The base of the rotating arm was insulated from the drive mechanism with gasket rubber, and the airfoil on the pitot tube was made of lead. The rotating arm was made of one inch standard pipe, and counterbalanced. There were undoubtedly some vibrations of the pitot tube, but the authors doubt that those vibrations had any effect on the data.

The error in reading pressure was constant, while percentage error based on $\frac{1}{2}\rho V^2$ increased rapidly as the speed of the tube through the fluid was decreased. The data at speeds lower than two feet per second are therefore not considered too reliable unless they faired in with or overlapped higher speed data. It was not possible to obtain data at the lowest Reynold's numbers at higher speeds because the supply of viscous oil was exhausted, and time did not permit a more conclusive investigation in this range.

The screen baffles introduced a possible interference to the pressure field surrounding the pitot tube. The baffles were at least ten diameters away from the pitot tube. Error caused by interference of the pressure field by the baffles is believed to be negligible.

FINDINGS

The results of the authors' investigation is given on Figure XI along with the results of other investigators. The curves representing results of other investigators are curves they suggested to fit their data. From Figure XI, it would appear that the authors' results are not supported by those of other investigators.

Barker's data was given in (3) as she recorded it, and in Figure XII as she plotted it. The authors transformed Barker's data to $\frac{p_x}{\frac{1}{2}\rho V^2}$ versus Reynold's number and plotted the quantities derived on Figure 10. It may be seen that when presented in this manner, Barker's data and that of the authors is in fairly close agreement, even on an expanded scale. Calculations for transformation of Barker's data was done by slide rule and is included as Appendix C.

It is interesting to note that the authors' results appear to follow Tsien's analysis[1] down to a Reynold's number of 200. For Reynold's numbers below 200 the results support Chambré's analysis[2].

Homann's results from (4) were not presented as taken, so his experimental data could not be transformed for comparison. Homann indicates that his results follow the curve Barker suggested for her results down to a Reynold's number of 2, as illustrated on Figure XI.

The results of the Gerdes, Brooks, and Kalina (see Figure XI and Figure XIII)[5] investigation do not compare too well with the results of the authors. However, since the data at low Reynold's numbers was obtained at low speeds, the authors do not consider their results reliable enough in this range to repute the results of Gerdes, Brooks, and Kalina[5]:

The authors find that below Reynold's numbers of 35 pitot tube data must be corrected to eliminate pressures caused by viscous forces prior to using Bernoulli's equation to calculate the dynamic head. If correction for viscous forces is not made, use of the Bernoulli equation results in an error of 1 per cent at Reynold's numbers of 35; and as Reynold's numbers are decreased, the error increases and reaches a magnitude of 50 per cent at a Reynold's number of 5.

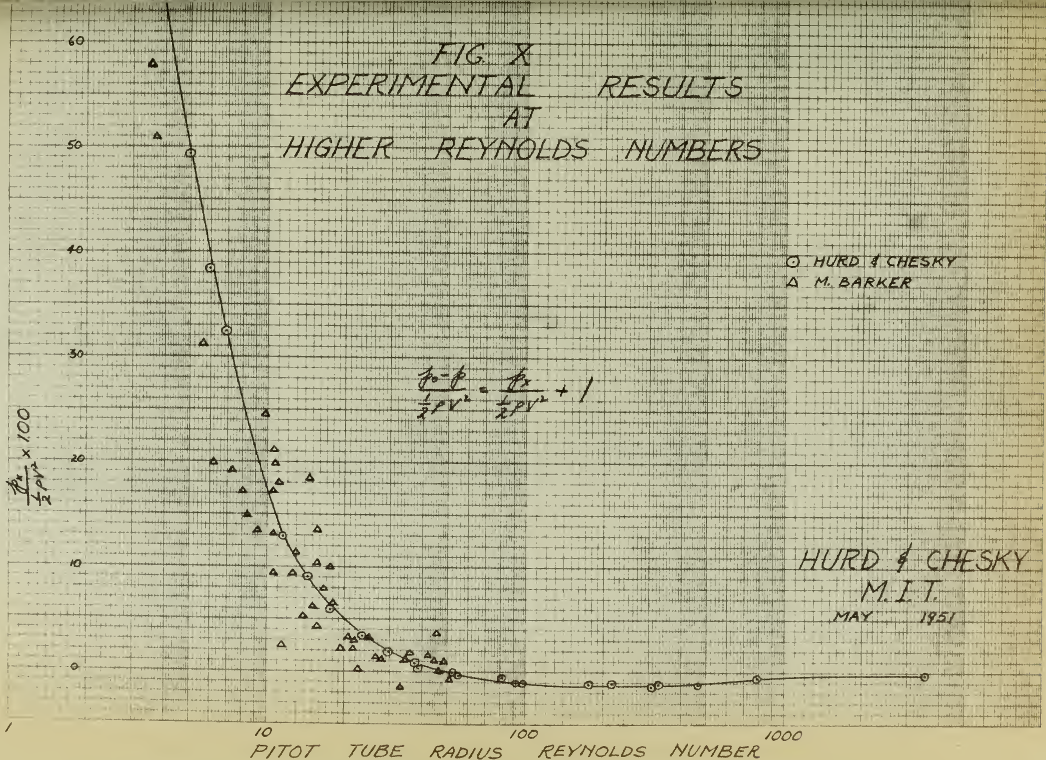


FIG. X
EXPERIMENTAL RESULTS
AT
HIGHER REYNOLDS NUMBERS
$\frac{p_0 - p}{\frac{1}{2}\rho V^2} = \frac{p_x}{\frac{1}{2}\rho V^2} + 1$
⊙ HURD & CHESKY
Δ M. BARKER
HURD & CHESKY
M.I.T.
MAY 1951
$\frac{p_x}{\frac{1}{2}\rho V^2} \times 100$
60
50
40
30
20
10
0
1
10
100
1000
PITOT TUBE RADIUS REYNOLDS NUMBER

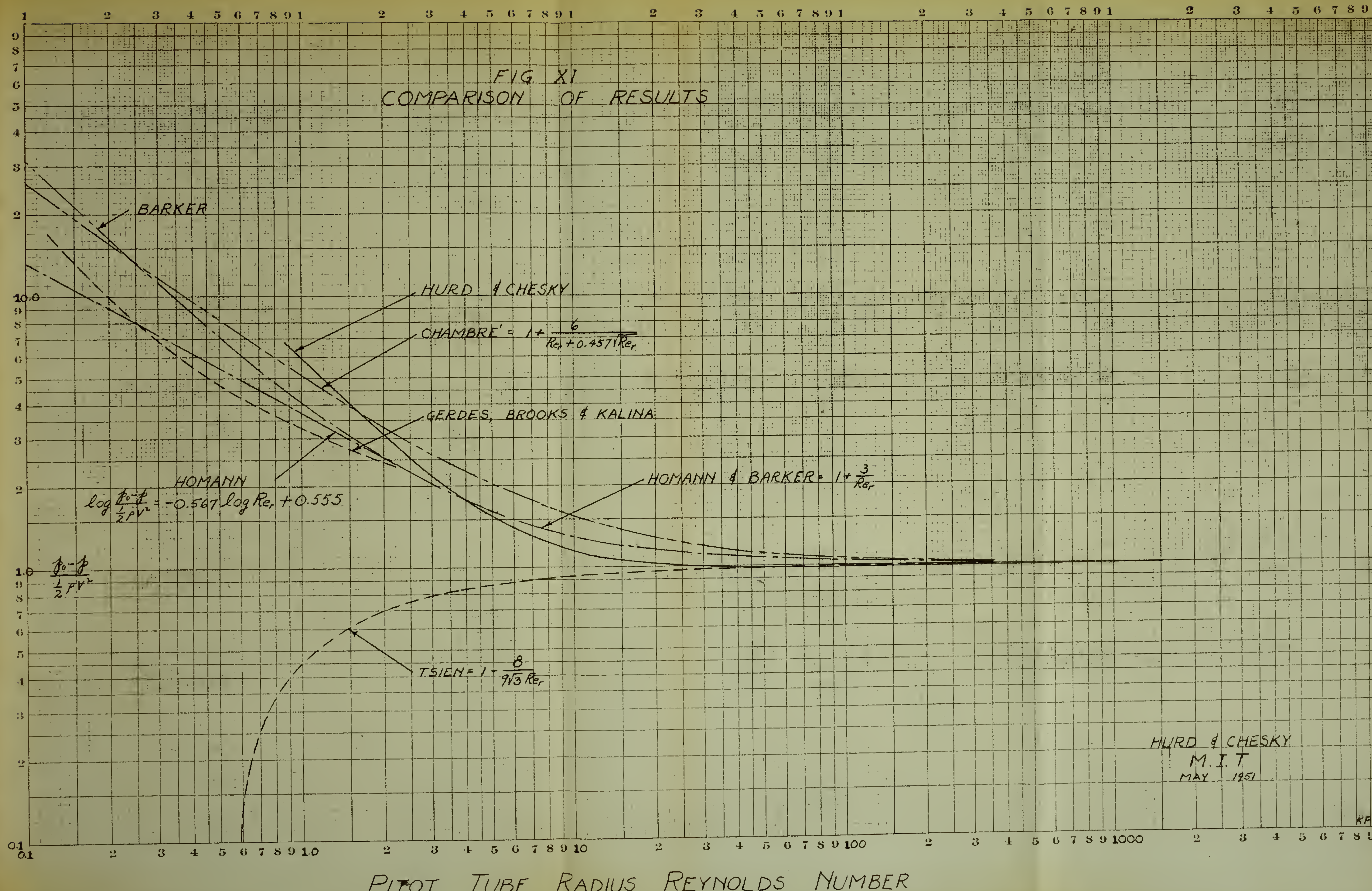
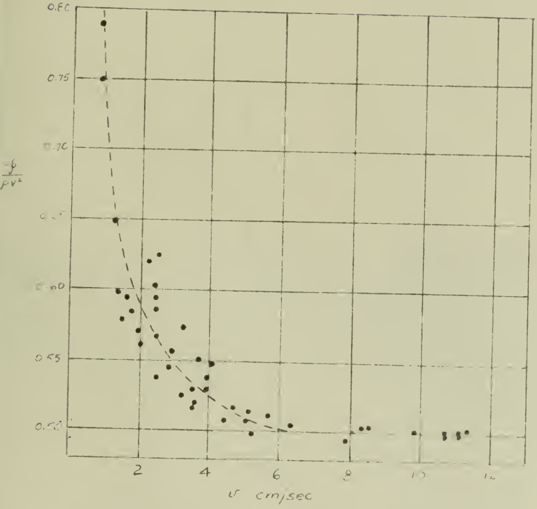


FIG XI
COMPARISON OF RESULTS
BARKER
HURD & CHESKY
CHAMBRE' = $1 + \frac{6}{Re_r + 0.457\sqrt{Re_r}}$
GERDES, BROOKS & KALINA
HOMANN
$\log \frac{p_0 - p}{\frac{1}{2}\rho V^2} = -0.567 \log Re_r + 0.555$
HOMANN & BARKER = $1 + \frac{3}{Re_r}$
$\frac{p_0 - p}{\frac{1}{2}\rho V^2}$
TSIEN = $1 - \frac{8}{9\sqrt{3}\, Re_r}$
HURD & CHESKY
M.I.T
MAY 1951
KFC
PITOT TUBE RADIUS REYNOLDS NUMBER

Fig. XII

Experimental Results of M. Barker



v = velocity at centre of pipe = twice mean velocity of outflow

p = pressure difference between pitot and static tubes

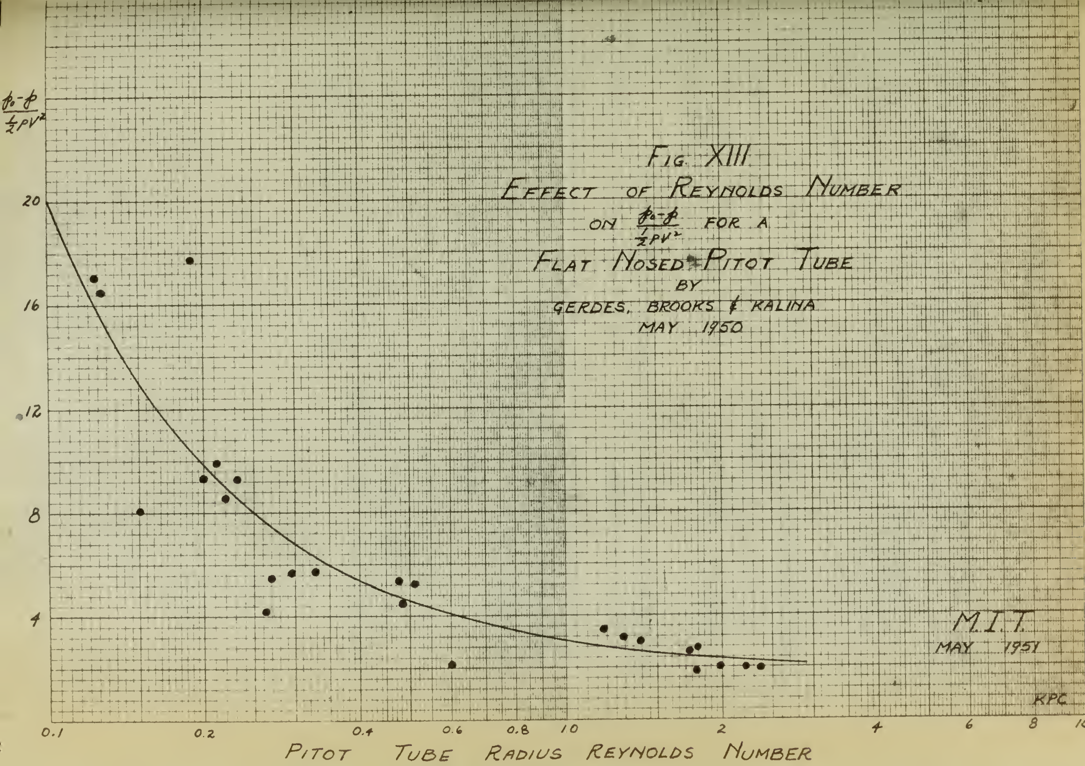


FIG. XIII
EFFECT OF REYNOLDS NUMBER
ON $\frac{p_0 - p}{\frac{1}{2}\rho V^2}$ FOR A
FLAT NOSED PITOT TUBE
BY
GERDES, BROOKS & KALINA
MAY 1950
M.I.T.
MAY 1951
KPC
$\frac{p_0 - p}{\frac{1}{2}\rho V^2}$
20
16
12
8
4
0.1
0.2
0.4
0.6
0.8
1.0
2
4
6
8
10
PITOT TUBE RADIUS REYNOLDS NUMBER

SUGGESTIONS FOR FUTURE WORK

It is suggested that apparatus and procedure similar to that used by the authors could be utilized to determine the effect of geometry of the pitot tube at low Reynold's numbers. It could well be that the effect of viscosity will vary considerably with the shape of the pitot tube.

It would also be desirable for future investigators to procure a sufficient supply of heavy oil, and investigate the effect of viscosity at Reynolds numbers below 5 at speeds higher than those attained by the authors.

Before utilizing apparatus of this type for further investigation, the authors suggest effort be made to eliminate the rotation of the fluid in the trough by full baffles actuated to move clear of the pitot tube as it passes the baffle, and then block the full cross section of the tank when the tube has passed. Other ideas may be developed by future investigators to do the same thing.

Some method should be devised to maintain the speed of the rotating mechanism constant by utilizing a feed back circuit or a constant voltage source. This will save much time in taking data, and reduce a potential source of error.

APPENDIX A

SUMMARY OF DATA AND CALCULATIONS

$R = 59\frac{43}{64}$ in. $g = 32.173$ ft/sec^2

Sample	Time T	No. of Rev. N	Vel. V	Static Head h_s	Dyn. Head h_d	Head Change h	Temp t_f	SUS Viscosity μ	Kinematic Viscosity γ	Re No Re_r	$\frac{p_0-p}{\frac{1}{2}\rho V^2}$ %
#1	197	100	15.86	15.99	15.70	-0.29	83.5°	32.3	1.26	3500.	-0.24
#2	612.6	250	12.75	15.90	15.49	-0.41	84.2°	41.0	4.51	787.9	-0.53
#3	791.4	340	13.42	16.22	15.17	-1.05	81.8°	53.0	8.30	450.8	-1.22
#4	598.7	260	13.57	16.25	15.04	-1.21	80.0°	67.4	12.34	306.5	-1.39
#5	172.4	41	7.431	16.15	15.87	-0.28	82.2°	103.0	21.35	97.0	-1.07
#6	253.6	100	12.32	16.03	15.60	-0.43	81.2°	1900	42.34	81.1	-0.60
#7a	218.7	80	11.43	16.00	16.50	+0.50	80.8°	392.0	85.90	37.1	0.81
#7b	239.5	70	9.132	16.00	16.76	+0.76	80.8°	392.0	85.90	29.6	1.92
#7c	216.9	50	7.203	16.00	16.85	+0.85	80.8°	392.0	85.90	23.4	3.46
#7d	208.0	30	4.506	16.00	16.88	+0.88	80.8°	392.0	85.90	14.6	9.15
#7e	297.2	20	2.103	16.00	16.68	+0.68	80.8°	392.0	85.90	6.32	32.47
#7f	181.0	6	1.036	16.00	16.50	+0.50	80.8°	392.0	85.90	3.36	98.40
#8a	249.4	70	8.770	15.68	17.85	+2.17	82.8°	642	141.03	17.33	5.93
#8b	438.5	28	1.995	15.68	17.02	+1.34	82.8°	642	141.03	3.94	71.0
#8c	331.2	11	1.038	15.68	16.75	+1.07	82.8°	642	141.03	2.05	210.0
#8d	627.5	9	0.4481	15.68	16.20	+0.52	82.8°	642	141.03	0.89	547.0
#8e	390.7	40	3.199	15.68	17.545	+1.865	80.0°	690	151.60	5.88	38.5
#8f	573.3	114	6.213	15.68	18.05	+2.37	80.2°	685	150.50	11.51	12.9
#8g	353.6	30	2.651	15.68	17.325	+1.645	80.4	680	149.40	4.95	49.4
#9a	302.7	60	6.193	16.38	16.43	+ .05	80.0°	209	48.60	38.1	+0.28
#9b	277.6	80	9.004	16.38	16.19	-0.19	80.5°	207	48.32	55.9	-0.49
#9c	342.4	160	14.60	16.38	15.32	-1.06	81.0°	205	47.84	91.6	-1.05
#10a	256.1	17	2.074	16.37	16.37	0	81.0°	62.2	10.92	52.9	0.00
#10b	221.8	23	3.240	16.37	16.34	-0.03	81.0°	62.2	10.92	82.7	-0.60
#10c	185.0	41	6.925	16.37	16.12	-0.25	81.0°	62.2	10.92	177.0	-1.10
#10d	186.2	50	8.390	16.37	16.02	-0.35	81.5°	62.0	10.87	216.0	-1.05
#10e	122.5	50	12.75	16.37	15.60	-0.77	81.5°	62.0	10.87	327.0	-1.02

APPENDIX B

SAMPLE CALCULATIONS

Sample #1

$t_f = 83.5^\circ F \qquad \mu = 32.3\ SUS$

$\gamma = 0.226\,t - \frac{135}{t}$ where $t = SUS$

$\gamma = 7.2998 - 6.0372 = 1.2626$ centistokes

$\gamma = 1.2626$ centistokes $\times\ 1.0764\times10^{-5}\ ft^2/sec$ per centistoke $= 1.3591\times10^{-5}\ ft^2/sec$

$$V = \frac{2\pi RN}{T} = \frac{2\times3.1416\times4.9727\,ft\times100}{197\,sec} = 15.8601\ ft/sec$$

$$Re_r = \frac{Vr}{\gamma} = \frac{15.8601\ ft/sec\times0.003\ ft}{1.3591\times10^{-5}\ ft^2/sec} = 3500.1$$

$$\Delta h = -(h_s - h_d)$$

$$p_x = \rho g\Delta h$$

$$\frac{p_x}{\frac{1}{2}\rho V^2} = \frac{\rho g\Delta h}{\frac{1}{2}\rho V^2} = \frac{2g\Delta h}{V^2} = \frac{2\times32.174\times\Delta h}{V^2\times2.54\times12} = \frac{2.1111\times\Delta h}{V^2}$$

$$= \frac{2.1111\times-0.29}{(15.8601)^2} = -0.002434$$

$$= -0.002434\times100 = -0.2434\%$$

To convert above into $\frac{p_0 - p}{\frac{1}{2}\rho V^2}$ as used by other investigators

$p_0 = p_x + p_v + p \qquad p_v = \frac{1}{2}\rho V^2$

$$\frac{p_0 - p}{\frac{1}{2}\rho V^2} = \frac{p_x + p}{\frac{1}{2}\rho V^2} = \frac{p_x}{\frac{1}{2}\rho V^2} + 1 = 1.002434$$

APPENDIX C

DATA AND CALCULATED RESULTS OF M. BARKER

(Converted to Re_r & $\frac{p_0 - p}{\frac{1}{2}\rho V^2}$)

Temp	$V_{cm/sec}$	$(p_0 - p)\frac{dynes}{cm^2}$	Re_r	$\frac{p_0 - p}{\frac{1}{2}\rho V^2}$	$\frac{p_x}{\frac{1}{2}\rho V^2} \times 100$
13°C	0.82	0.53	3.42	1.582	58.2
	1.35	1.19	5.64	1.312	31.2
	2.35	3.43	9.82	1.245	24.5
	3.12	5.41	13.00	1.114	11.4
	3.96	8.44	16.50	1.079	7.9
	5.24	13.70	21.80	1.003	0.3
	7.90	30.75	32.90	0.988	-1.2
	11.14	62.10	47.60	1.003	0.3
14°C	2.51	3.56	10.7	1.133	13.3
	3.58	7.25	15.25	1.138	13.8
	5.09	13.19	21.70	1.022	2.2
	6.23	19.65	26.60	1.015	1.5
	8.38	35.50	35.70	1.013	1.3
	11.34	64.90	48.40	1.002	0.2
14°C	1.58	1.15	6.75	0.925	-7.5
	1.95	2.175	8.34	1.148	14.8
	2.45	36.25	10.46	1.212	21.2
	4.07	9.10	17.39	1.10	10.0
	11.12	62.00	47.5	1.008	0.8
14.2°C	3.21	5.41	13.77	1.053	5.3
	3.695	7.52	15.88	1.105	10.5
	5.15	13.60	22.10	1.030	3.0
	10.73	58.05	46.20	1.012	1.2
14.6°C	2.42	3.42	10.47	1.172	17.2
	2.55	4.08	11.03	1.260	26.0
	3.52	6.59	15.20	1.063	6.3
	5.67	16.50	24.50	1.032	3.2
	10.65	58.80	46.10	1.038	3.8

APPENDIX C (CONTINUED)

Temp.	$V_{cm/sec}$	$(p_0 - p)\ \frac{dynes}{cm^2}$	Re_r	$\frac{p_0 - p}{\frac{1}{2}\rho V^2}$	$\frac{p_x}{\frac{1}{2}\rho V^2} \times 100$
15°C	0.84	0.53	3.68	1.510	51.0
	1.70	1.72	7.46	1.193	19.3
	1.84	1.98	8.08	1.172	17.2
	2.44	3.56	10.72	1.200	20.0
	2.46	3.30	10.80	1.095	9.5
	2.51	3.70	11.02	1.180	18.0
	3.32	6.33	14.56	1.188	18.8
	3.96	8.30	17.38	1.062	6.2
	4.74	11.60	20.80	1.034	3.4
	6.34	20.30	27.80	1.012	1.2
	8.42	35.90	36.90	1.016	1.6
	9.87	49.30	43.30	1.016	1.6
	11.11	62.00	48.80	1.010	1.0
15°C	1.41	1.19	6.20	1.200	20.0
	2.05	2.375	9.10	1.135	13.5
	2.87	4.48	12.60	1.093	9.3
	3.60	6.725	15.80	1.042	4.2
	4.44	10.01	19.50	1.022	2.2
	11.76	68.75	51.70	0.998	-0.2

APPENDIX D

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